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Simulation Modeling in Lean Programs

This presentation provides examples where simulation modeling was used as a tool in lean improvement programs, as a complement to other techniques such as value stream mapping and kaizen.

It is particularly valuable in operations where a mix of products share resources, and it is difficult to "get your head around" all the things that are happening asynchronously, even in an operation with only moderate complexity.

Takeaways from this presentation include

- Simulation utilizes real historical data to test lean changes in advance of implementation.
- It is valuable for evaluating things that other tools cannot, such as product mix, setups, variability in processes, downtimes, demand patterns, etc.
- Employees such as lean analysts, engineers, planners or six sigma black belts can be trained to use and develop these types of models. Modeling can become another tool in their toolbox.

There are sometimes objections in the lean community to using software solutions in lean manufacturing analysis. In this case, simulation modeling is a valuable complement to, rather than a replacement for, the traditional tools. For example, value stream mapping is a key tool; it is a good beginning. But it is static and typically only done for high-volume products or classes of products. Simulation allows the value stream map to become dynamic, and to model the range of probable values—not just averages. It also allows linkages to other tools such as projected capacity utilization in a consistent manner.

The presentation includes some background to describe simulation, and it has two examples of lean projects that used models for testing. One of the examples is for a lean analysis of a factory, and the other is for a supply chain network.

SIMULATION: WHAT & WHY

Simulation refers to a software program, and there are different types and uses of it within manufacturing. This presentation refers to "discrete simulation" that allows one to visually see and measure how processes perform over time, including materials, information, and financial flows, and how probabilistic variables impact them. A discrete simulation program tracks all attributes of something such as a production order or customer order. Attributes may include line-item codes and amounts, as well as time stamps associated with processing.

It is common to use simulation to evaluate available capacity, particularly where there are many products involved. It is also common to use it to evaluate balancing of demand with supply, with either make-to-stock inventory or make-to-order lead times to consider.

Models also take statistical variability into account for demand, processing times and yields, setups, and unplanned downtimes that are important, real-world considerations. The term "monte carlo" simulation refers to this injection of statistical variability into the model runs.

SOME TYPICAL REAL BENEFITS

Some benefits I have seen companies achieve with simulation modeling as part of their approach include

- improvement in service level with inventory reductions
- shift/work center changes
- reduction in manpower needed for an operation
- end-to-end cycle time improvement
- measurement of impacts of late materials on downstream operations
- measurement of variability and product mix impacts on capacity.

LEAN PROJECT DEMONSTRATIONS

The two example projects presented include an improvement project for a plant that manufactures laminated plastic products, and a project to improve service level and inventory carrying cost for a network in Europe.

The projects incorporate lean techniques that are simulated and their effects measured, including

- kanbans
- schedules (batching vs. one-piece flow)
- EPEI (every-part-every-interval) rhythm cycles
- constant work-in-process (CONWIP)
- setup reduction
- routing changes
- shared resources
- postponement strategy.

PLASTICS PRODUCTS PLANT

The plant had a record of service-level problems in meeting demand, as well as higher overtime than budgeted. Management wished to implement a demand pull process to synchronize the work centers in the factory and ensure that anticipated volume increases could be met. **Figure 1** depicts the current manufacturing flow.

A team consisting of a black belt, work center supervisors, and planner created a value stream map of the process and action items to be implemented. They also implemented the 5S points of workplace organization and maintenance (structure, systematize, sanitize, standardize, self-discipline) tools in the work centers.

With some outside resource training and initial setup support, they configured and tested the simulation model. The analysis steps with model were

- Replicate current process metrics to validate the model.
- Analyze work shifts and responsibilities.
- Test a make-to-order mechanism for finished goods.
- Test kanbans for extrusion to replace the material requirements planning (MRP) trigger.
- The packaging operation was the critical constrained resource in the flow. A CONWIP mechanism to keep the packagers busy was tested. Since there were a variety of finished products and setup rules, an EPEI rhythm cycle was incorporated to deal with that.

Interesting perspectives and learnings evolved as the team reviewed results. For example, the planner/scheduler noticed the impact of set time required after the second step (lamination) before the plastic was cut, and proposed that it be done immediately after the first step of extrusion, rather than putting the rolls in inventory. The team then theorized that there was enough time to do it this way with the same work crew. This was then tested as a scenario and reviewed with the work crew.

Figure 2 depicts the new process that evolved and was tested.

The most challenging issue in the process was development of scheduling/replenishment rules for finished goods. There were 60+ finished products defined by specific combinations of lamination, cutting and finishing, and packaging. So converting to a demand pull with no finished inventory with the constraints of setups, and limited storage in front of packaging, was tested with a variety of scenarios. The resulting process met the lead time requirements for finished orders, with the combination of an EPEI rhythm cycle, and a CONWIP rule so that the packaging operation was not starved.

Figure 3 contains an example of before and after metrics that show the difference in demand fulfillment and utilization of the critical packaging resources. As the EPEI cycle was improved, the service level was also further improved (fewer backorders).

The simulation model provided the lean metrics to the team as "what-if" changes were made to the model. The analysis of the impacts of the range of variability in processing times, material lead times, yields and scrap, as well as unplanned downtime, were all important to the credibility of the results. The model provided metrics on performance vs. the takt times required, end-to-end cycle times, and overall equipment effectiveness (OEE). **Chart 1** shows how OEE was calculated. **Figures 4 and 5** show some example metrics from the model.

EUROPEAN SUPPLY CHAIN

This example demonstrates the use of a simulation model, in conjunction with a lean analysis methodology, to improve a supply chain network in Europe. The operation had poor service levels, with some products/countries fulfilling only about 50 percent of orders. This resulted in lost revenue since the products were available from competitors.

The supply chain and manufacturing management teams were also concerned about the excessive amount of inventory in the network.

The network consisted of a plant in Germany, six country-level distribution centers, and approximately 2,000 customers. Each country required that a unique label be applied to the exterior of the package. Each product was manufactured, packaged, and labeled in the German plant at the time of manufacture.

There were a total of 198 unique products (stockkeeping units) with the country labels applied. One of the lean concepts that the team wanted to evaluate was the impact of "postponement", i.e., delaying final product configuration.

If the final labeling could be postponed, the plant would only have to plan and manufacture 58 packaged products with plain "white labels." The white-label product could be stored in that form and then labeled only when needed.

ANALYSIS PROCESS

A benefit of using simulation is the ability to understand the impact of variability. In this case, there was significant variability not only in demand, but also in the frequency of production. **Figure 6** depicts the types of variability that exist in both amounts and time intervals for both supply and demand. That impacts the amount of safety stock required for a given product.

The approach taken was to use a proprietary methodology to categorize the production lead times and consistency of those times for each product, and to categorize the demand by volume and variability. A good statistic to measure relative variability is the coefficient of variation (CoV), which is computed as the standard deviation (SD)/mean. In this case, weekly SD and mean were used.

The impact of lead time and demand variability on how much safety stock (SS) is required can be demonstrated by **Chart 2**. It shows how the amount of SS varied to achieve the same level of service as lead time and demand variability increases. It should be noted that the chart assumes no variability in lead time.

Actually, there is variability in lead time, so that is one of the reasons simulation is used.

METHODOLOGY

The proprietary methodology used consisted of a several step analytical process to categorize the products based on demand volume, demand variability, inventory cost, and production/supply. **Charts 3 – 6** summarize these data.

The analysis also consisted of consideration of unit costs by product, since there was a wide variation in the unit costs. The operational cost of a separate labeling step was also considered, as well as the one-time capital investment cost to create a separate labeling facility. The result was a proposed design to manage the supply chain as three channels:

- A high-volume channel included 14 country labeled products and accounted for 66 percent of volume, 26 percent of inventory. These products would be produced biweekly.
- A high-cost channel included 23 "white label" products and accounted for 18 percent of volume but 63 percent of inventory. These products would be produced every four to eight weeks depending on volume. Kanbans for country labeled stock would drive the labeling process.
- Low-volume/low-cost channels were the remainder, with 16 percent of volume, 11 percent of inventory. These would be produced every six months and were products spread over the year.

Chart 7 summarizes the channel breakout to be tested.

SIMULATION

Separate sets of simulations were run for each channel using a replenishment model, as shown in **Figure 7.**

For each channel, safety stock requirements by product were first estimated using a formula-based approach. Then sets of monte carlo simulations were run to test the service levels with the estimates. In cases where statistical variations resulted in lower than expected service levels, the safety stocks or production frequency were changed. **Chart 8** shows the results of this for the high volume channel products.

The simulations included both the safety stock and cycle stock required to support the replenishment cycles. The resulting inventory cost could then be compared to a baseline actual inventory value.

The results of the simulations follow:

- The high-volume channel products with level biweekly supply showed service levels close to 100 percent, with 60 percent less inventory vs. the baseline.
- The high-cost channel with postponement showed that, on average, service levels of 97+ percent could be reached with 30 percent less inventory than the baseline.
- The low-volume/low-cost products with consistent production patterns could result in improved service levels at about the same level of inventory.

Chart 9 shows the overall service levels from the simulation for all countries and all products

Within the high volume channel, further analysis of the products and customers who purchased them was conducted. Some of the highest-volume customers with consistent volumes were selected for direct delivery form the plant, bypassing the country inventory.

POSTPONEMENT RESULTS

For the high-cost products selected for possible postponement of labeling, the simulation showed a benefit resulting from the combination of shortened/consistent lead times, and the reduced variability in the aggregated demand (at the European "white label") level.

For example, one product sold in seven countries had CoVs ranging from .95 to 2.85 at the country level and was replenished by the plant only semi-annually for most countries.

The new process for this product had white label product produced every six weeks, and the CoV Europe-wide was 65. **Chart 2** shows the relative differences in stock required to provide 98 percent service for this product.

The kanbans set up for labeled stock were pallet sizes for each product, and lead times to label and ship were one week.

The simulation showed that for this product about a 98 percent service level to the end customer demand could be achieved with about 28 percent less inventory, considering both safety stock and cycle stock.

SUMMARY

A model supported methodology such as the one described includes a traditional continuous improvement program, where the multi-functional team uses the model to test scenarios and evaluates the relative benefits of process changes. Models have also been shown to have continuing value for decisions about how to schedule an operation, or capacity planning for the operation, using a baseline set of volumes with incremental changes.

The examples in this presentation are from models developed by OpStat in Extend™, a discrete simulation program from Imagine That Inc. Many undergraduate and graduate programs are now including instruction in Extend to their students, so the learning curves for employees may not be as long as they might have previously.

I have been teaching graduate students to develop Extend models as part of supply chain design and lean manufacturing courses for five years. The students get about 15 hours of classroom instruction and several model building exercises in a semester. Most of the students are capable of modeling a simple manufacturing operation after that, and some have fairly advanced skills. It takes a person about a year to develop the expertise to develop a model from scratch for the type of operation described in this case study. On-the-job training and doing it is the most important aspect of gaining the experience.

ABOUT THE AUTHOR

Jim Curry is CEO of the OpStat Group and has consulted for multi-national companies in operations and supply chain improvement since 1987.

Example: Plastics Products
Test a Pull Process in a Flow Shop

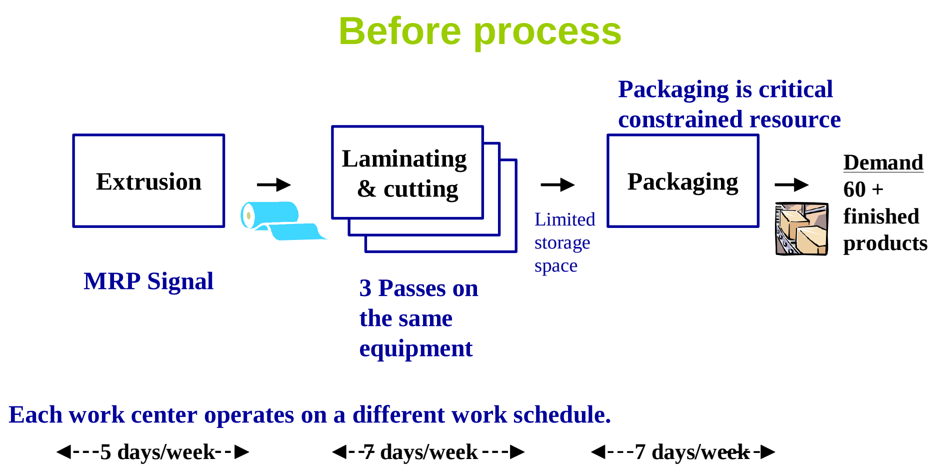


Figure 1. Plastics Products Plant

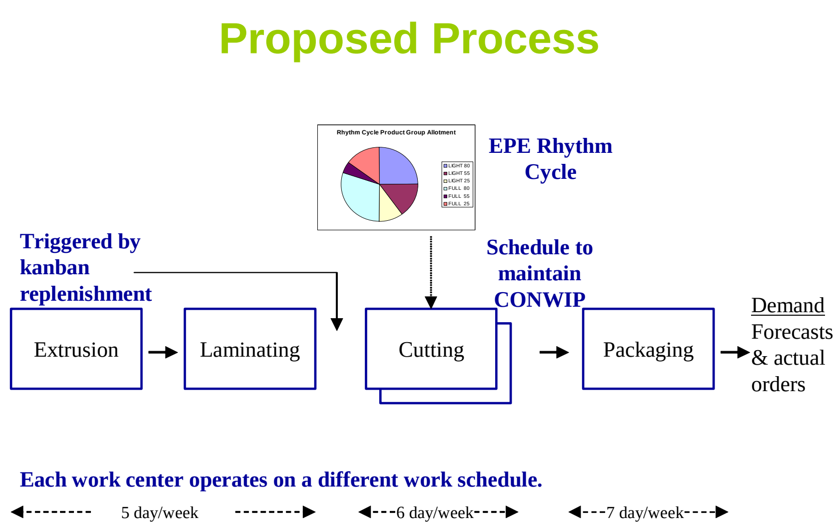


Figure 2. New Process

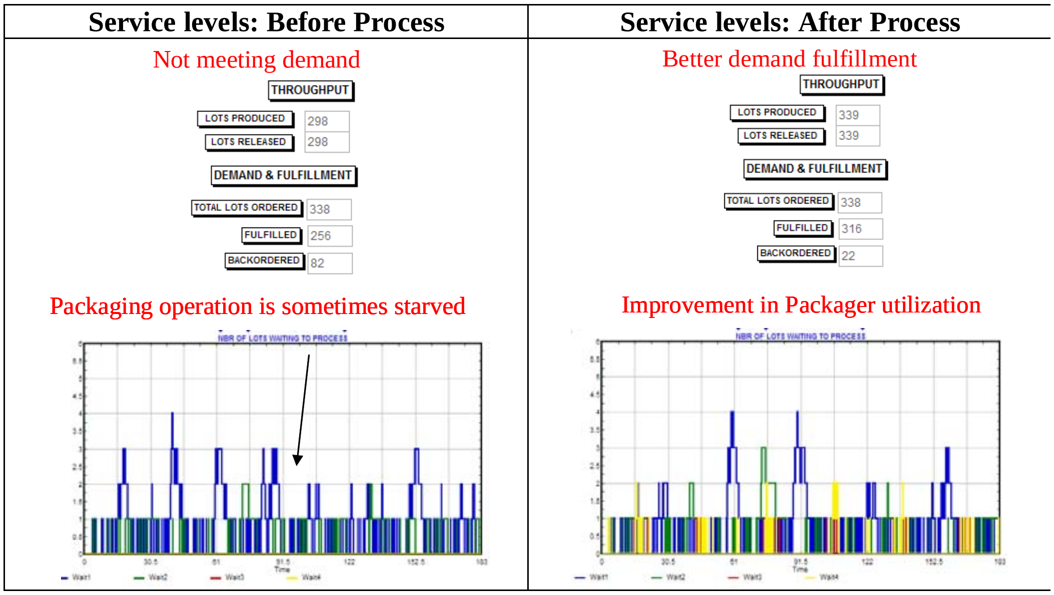


Figure 3. Differences in Fulfillment & Utilization

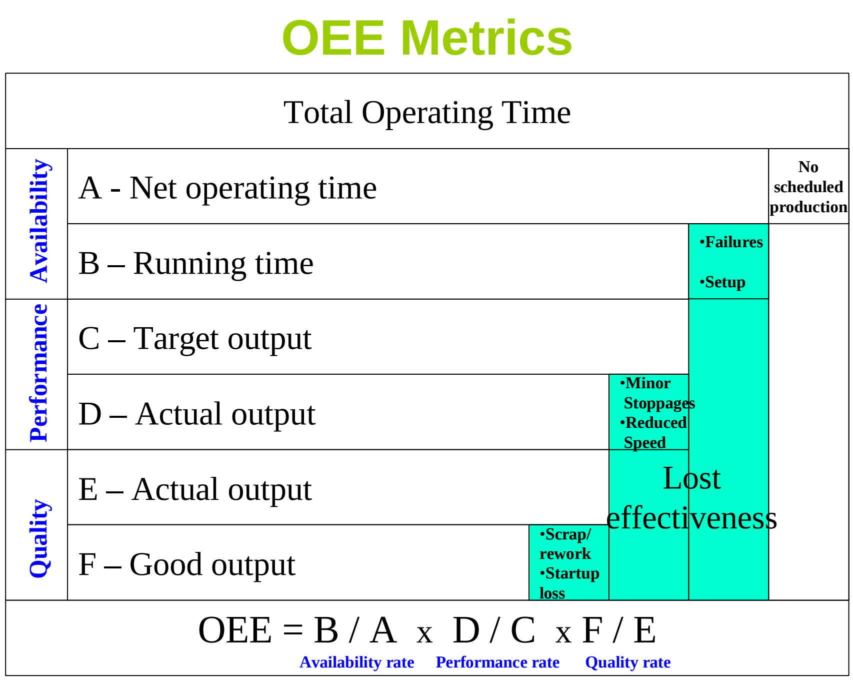


Chart 1. Calculation of Overall Equipment Effectiveness

Graphics Example

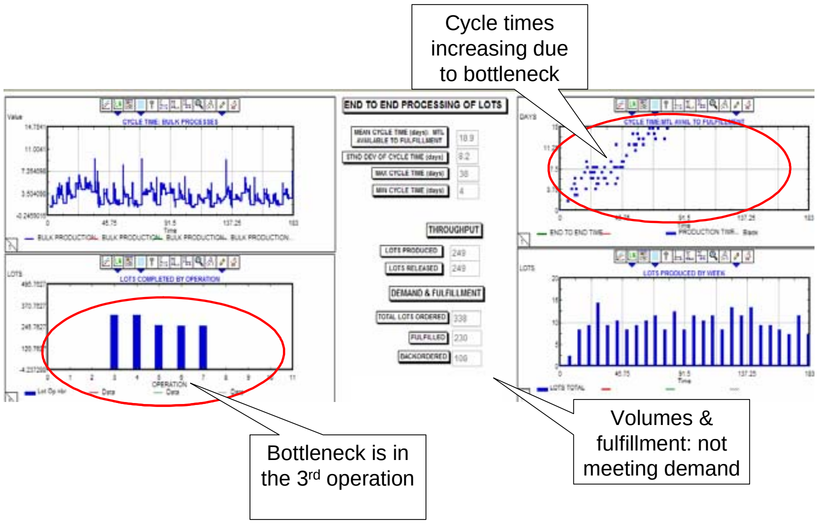
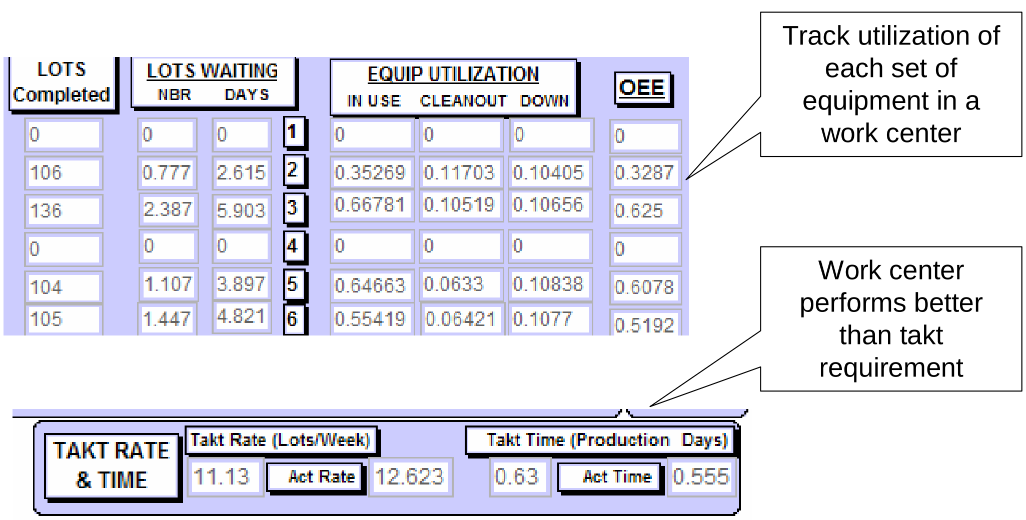


Figure 4. Graphical Output Example

Metrics Example



LOTS Completed	LOTS WAITING NBR	LOTS WAITING DAYS		EQUIP UTILIZATION IN USE	CLEANOUT	DOWN	OEE
0	0	0	1	0	0	0	0
106	0.777	2.615	2	0.35269	0.11703	0.10405	0.3287
136	2.387	5.903	3	0.66781	0.10519	0.10656	0.625
0	0	0	4	0	0	0	0
104	1.107	3.897	5	0.64663	0.0633	0.10838	0.6078
105	1.447	4.821	6	0.55419	0.06421	0.1077	0.5192

TAKT RATE & TIME	Takt Rate (Lots/Week)	Act Rate		Takt Time (Production Days)	Act Time	
	11.13	Act Rate	12.623	0.63	Act Time	0.555

Figure 5. Lean Metrics Example

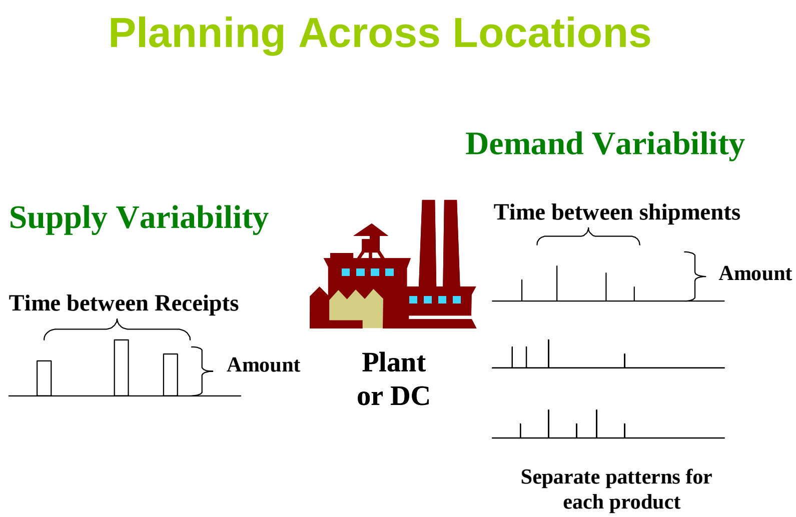


Figure 6. Supply & Demand Variability

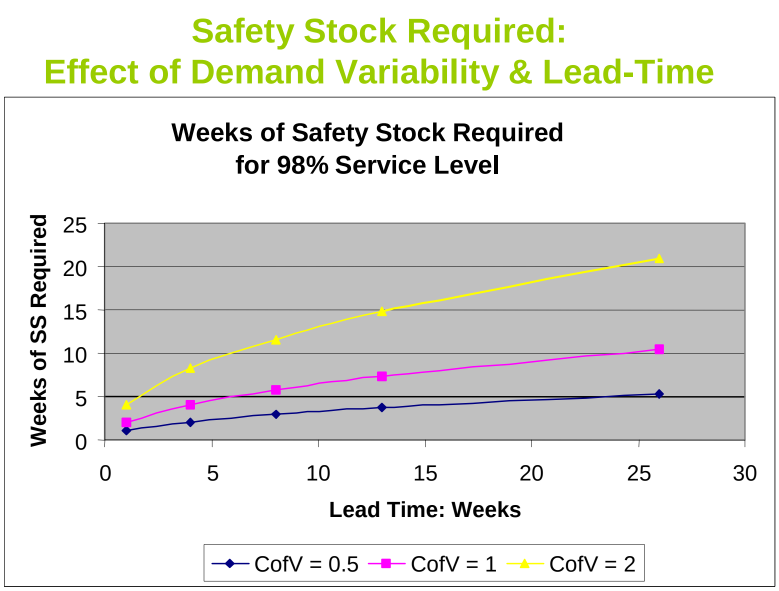


Chart 2. Safety Stock Required

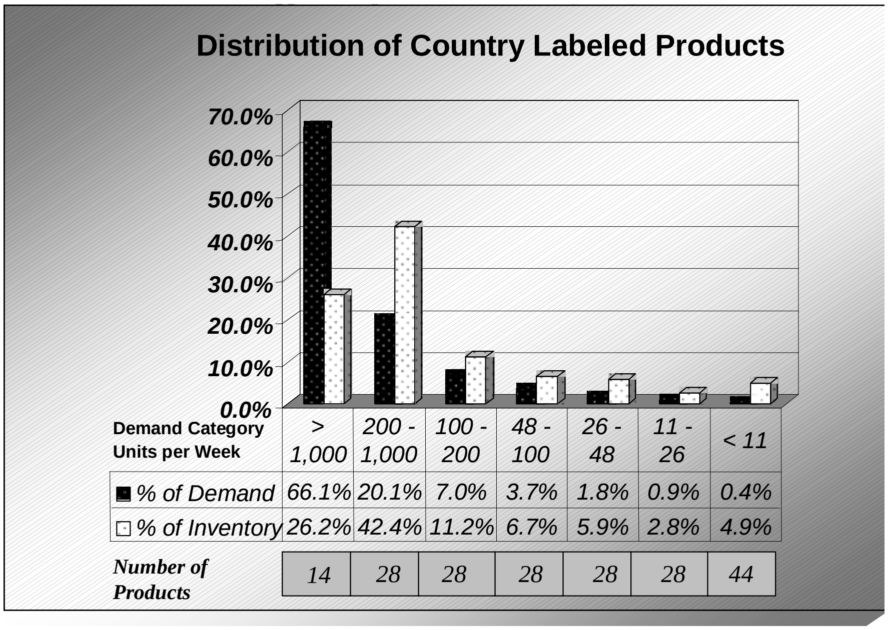


Chart 3. Product Demand & Inventory

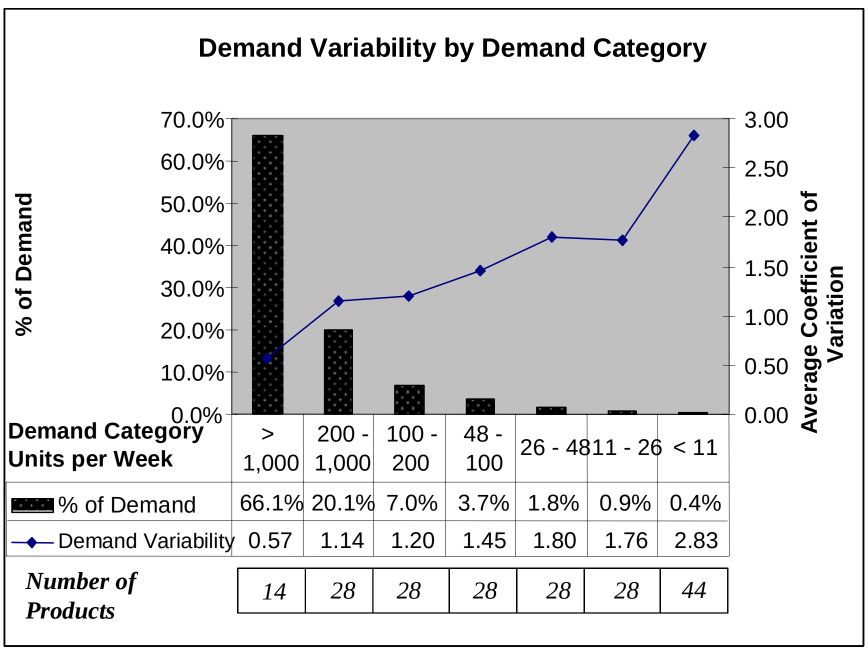


Chart 4. Demand Categories & Variability

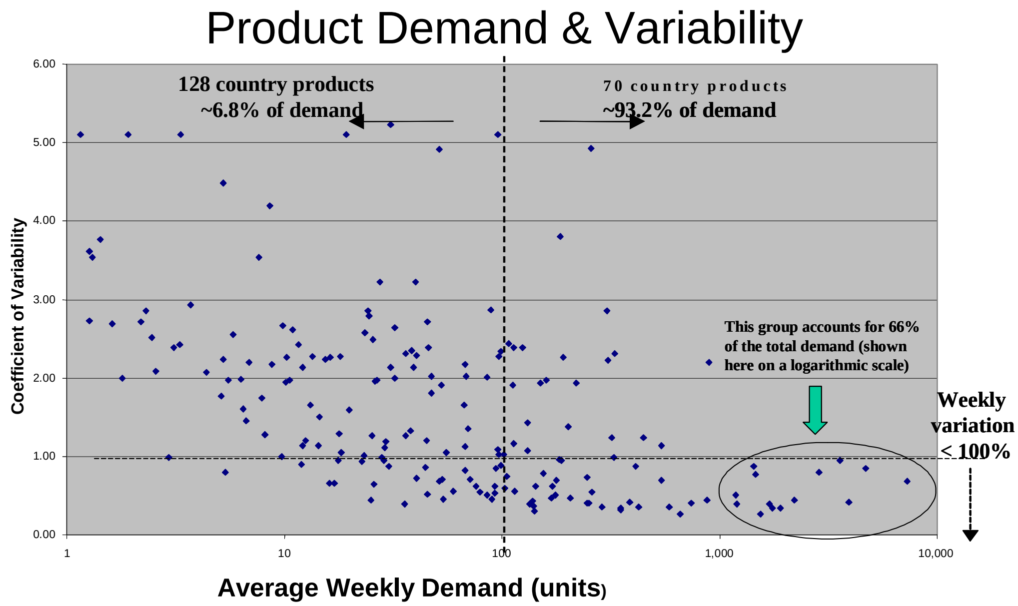
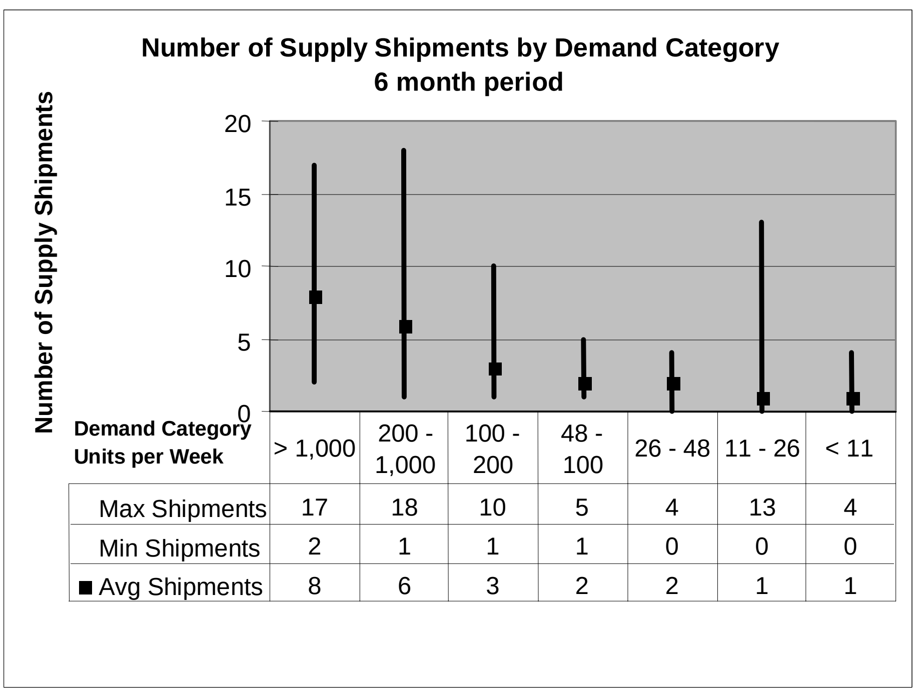


Chart 5. Demand & Variability by Product



Demand Category Units per Week	> 1,000	200 - 1,000	100 - 200	48 - 100	26 - 48	11 - 26	< 11
Max Shipments	17	18	10	5	4	13	4
Min Shipments	2	1	1	1	0	0	0
■ Avg Shipments	8	6	3	2	2	1	1

Chart 6. Plant Supply Variability

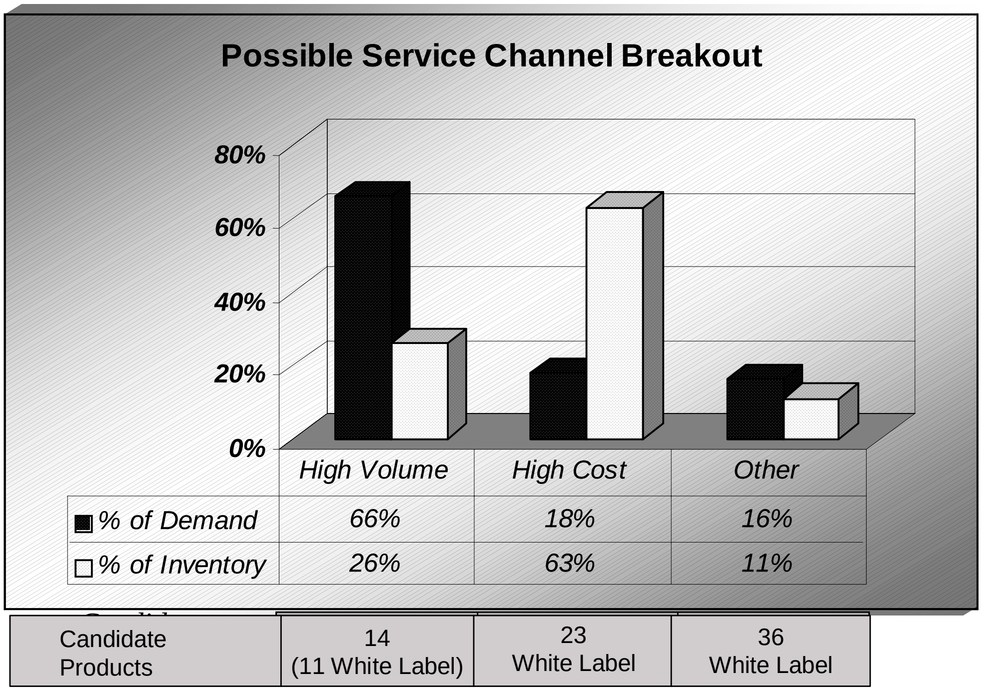


Chart 7. Channel Segmentation

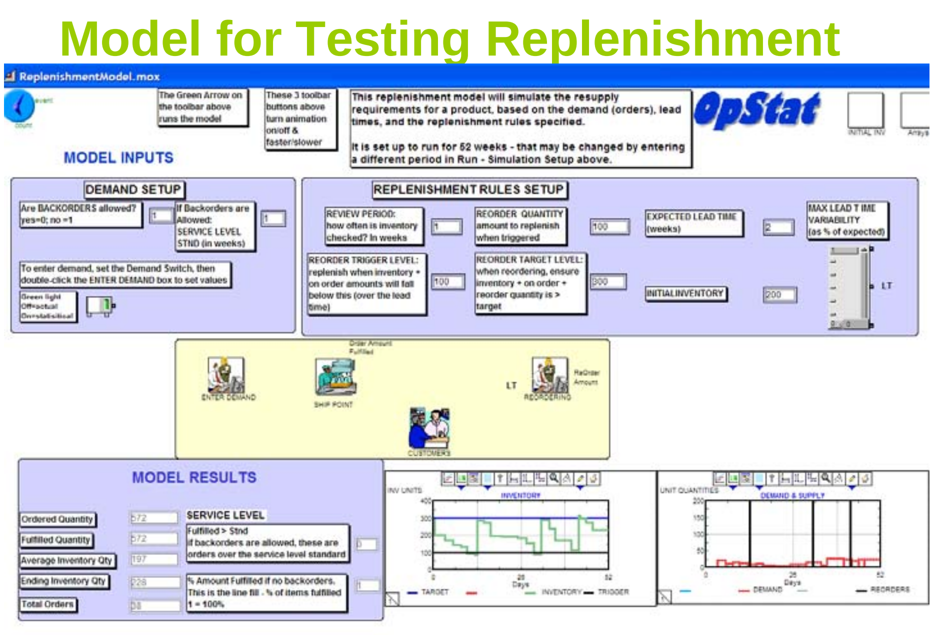


Figure 7. Replenishment Model

Product	Country	Level Load Weeks SS	Extra Buffer Weeks	Total Weeks SS
	DE	2.7	0	2.7
	ES	5.0	0	5.0
	IT	3.1	2	5.1
	DE	2.4	1	3.4
	DE	3.7	3	6.7
	DE	2.5	2	4.5
	IT	2.5	2	4.5
	DE	2.3	2	4.3
	IT	3.9	0	3.9
	DE	2.8	0	2.8
	ES	2.5	1	3.5
	IT	3.1	0	3.1
	DE	3.4	0	3.4
	IT	6.5	0	6.5

Chart 8. Simulation Adjustments to Safety Stock Estimates – High Volume Channel

TOTAL DEMAND & SERVICE LEVELS BY COUNTRY

		AT	BE	DE	ES	FR	GB	IT	NL	SE
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	0	60477	1544	572206	209295	23263	40225	488486	5261	45532
1	0	0.99	0.968	0.998	0.995	0.918	0.936	0.994	0.948	0.976

Chart 9. Overall Results